0785

PB 204 195

COMPUTER MAPPING
as an aid in
AIR POLLUTION STUDIES

VOLUME TWO: INDIVIDUAL REPORTS

REPORT J
BOSTON REGION STUDY

by
John C. Goodrich

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

A

51

BIBLIOGRAPHIC DATA SHEET	1. Report No. APTD-0785	2.	3. Recipient's Accession No.
4. Title and Subtitle Computer Mapping as an aid in Air Pollution Studies Volume Two: Individual Reports - Report J - Boston Region Study			5. Report Date April 1970 6.
7. Author(s) John C. Goodrich			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Graduate School of Design Harvard University Cambridge, Massachusetts 02138			10. Project/Task Work Unit No. 11. Contract/Grant No. 68A-2405D
12. Sponsoring Organization Name and Address National Air Pollution Control Administration U. S. Public Health Service U. S. Department of Health, Education, and Welfare Washington, D. C. 20201			13. Type of Report & Period Covered 14.

15. Supplementary Notes DISCLAIMER - This report was furnished to the Office of Air Programs by Graduate School of Design, Harvard University, Cambridge, Massachusetts 02138 in fulfillment of Grant No. 68A-2405D

16. Abstracts

A detailed report is presented on the results of the Boston Region Study as aided by computer mapping. The report is divided into two sections: Data and base maps; and Mapping air quality and emissions data. An introduction discusses the research methodology, some of the technical considerations, and the applicability to control agency programs.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Computer programs
Mapping
Maps
Emission
Data analysis
Particles

17b. Identifiers/Open-Ended Terms

Boston
Particulates

17c. COSATI Field/Group 13B

18. Availability Statement Unlimited	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 51
	20. Security Class (This Page) UNCLASSIFIED	22. Price 3.00 - 0.95

FORM NTIS-35 (10-70) USCOMM-DC 4[illegible]

LABORATORY FOR COMPUTER GRAPHICS
AND SPATIAL ANALYSIS

Graduate School of Design
Harvard University
Cambridge, Massachusetts

This report was funded by:

Demonstration Grant 68A-2405D
National Air Pollution Control Administration
U. S. Public Health Service
U. S. Department of Health, Education, and Welfare

John C. Goodrich, Editor
Gail Howrigan, Associate Editor

Rosalie Alexander
Carol Chase
Candace Howes
Whitmore John
Linda Peacock

April 1970

COMPUTER MAPPING

as an aid in

AIR POLLUTION STUDIES

Personnel

Principal Investigators

Howard T. Fisher	Project Director (Associate Director of The Laboratory for Computer Graphics and Spatial Analysis)
John C. Goodrich	Associate Project Director
William Warntz	(Director of The Laboratory for Computer Graphics and Spatial Analysis)
Allan H. Schmidt	(Associate Director of The Laboratory for Computer Graphics and Spatial Analysis)

Case Study Investigators

Norma Bogen	St. Louis Project
Paul Jack Dangermond	California and Puget Sound Studies
Steven Fosburg	Statistical Investigation
Jean Maurice Granger	Montreal Project
Donald Shepard	St. Louis Project/Program Investigation
Elia Werczberger	Kansas City Project

Programming Support and Development

Chang-I Hua
Lannon Leiman
Kathleen Reine

Research Assistants

Whitmore John
Johnny Kirkland
Helen Mansfield
Adrian Thomas

Ellen Bussard
Robert Cartwright
Katherine Mickey
Warnie Webster

Administrative and Secretarial Support

Malcolm Fitzpatrick
Gail Howrigan
Linda Peacock
Laurence Yont

Regina McDonald
Donna L. Moorhead
Claudia S. Rosen
Judith Strong

PREFACE

From July 1, 1968 through December 31, 1969, the Laboratory for Computer Graphics and Spatial Analysis conducted a demonstration of several conceptual, methodological, and technical approaches to problems in the field of air pollution, employing computer-produced maps and allied displays. This work was done under a grant (No. 68A-2405D) from the Division of Control Agency Development, National Air Pollution Control Administration (NAPCA), Public Health Service, U. S. Department of Health, Education, and Welfare.

The results of this study, taken in its entirety, should make an important contribution to the work of Federal, state, and local air pollution agencies, especially in their efforts to determine the best control strategies for use in air quality control regions. The computer is an ideal tool for relating and combining sets of data, and for considering alternatives. For instance, graphic displays can contribute significantly to the evaluation of both short-term and long-term control strategies.

In demonstrating "the use of computer graphics as a means for more clearly portraying data related to the sources, distribution, and community effects of air pollution," the primary emphasis was on case studies for specific areas. The secondary emphasis, to support and complement the case studies, included:

(a) "the development of instructional manuals covering the procedures required for the preparation and interpretation of computer maps of various kinds, as related to air pollution,"

(b) "the use of certain newly developed techniques for describing, analyzing, and portraying quantitative surfaces and movements relative to such surfaces, as related to air pollution," and

(c) "an appraisal of alternative equipment, techniques, and computer programs presently or potentially available for the production of computer graphic displays pertinent to air pollution."

The case study regions were selected in consultation with NAPCA. Considerations included:

(a) sufficient air quality, emission, and related socio-economic and meteorological data--spatially distributed over the region--to enhance the likelihood of adequately demonstrating the mapping techniques;

(b) representative problems in data handling and mapping so that the techniques demonstrated would have applicability to as many other areas as possible;

(c) special problems in data handling and mapping so that as many techniques as possible could be adapted, developed, and tested;

(d) areas of which NAPCA and the individual investigators had special knowledge and could therefore utilize relevant research to enhance the study;

(e) areas where an immediate interest in mapping had been expressed for on-going Federal, state, and local air pollution activities.

Other research was undertaken to support and complement the case studies, and, in particular, to provide:

(a) the widest possible distribution of the mapping programs and accompanying explanation of the techniques through

i) copies of the Laboratory's SYMAP Computer mapping program,
ii) an introductory correspondence course in the SYMAP program,
iii) general program description and supplementary explanation for the existing user-manuals;

(b) a general review of present and potential hardware, output devices, and programs applicable to computer graphic displays of air pollution and related data;

(c) means for predicting, projecting, and correlating air pollution and related data, utilizing the latest

knowledge in planning, geography, and spatial analysis in general;

(d) dissemination of information on approaches and techniques to Federal, state, and local air pollution agencies, especially for use in the air quality control regions.

The final report is divided into two parts: Volume One: Summary, and Volume Two: Individual Reports--the detailed reports on the case study areas and the technical reports related to other research undertaken. The pertinent graphic displays are included with the appropriate individual report and a complete set is provided with the Summary Volume.

Introductory sections describing the air pollution and related data used are provided in the major case study reports for St. Louis and Kansas City; these should be referred to by anyone unfamiliar with the types of data and problems existing in this field. Detailed discussions of special data handling and mapping techniques are presented either as appendices to case study reports, or in separate technical reports.

The Summary Volume includes a discussion of all the areas of research undertaken and contains the complete table of contents for the reports of Volume Two. This should provide a useful reference of the special problems and technical discussions of one report which may be of interest to the reader of another detailed report.

The Boston Region Study is presented here as Report J of Volume Two. It is divided into two sections--data and base maps, and mapping air quality and emissions data--in addition to an introduction discussing the research methodology, some of the technical considerations, and the applicability to control agency programs. An appendix of computer graphics produced is included.

The research discussed in this report was undertaken by John C. Goodrich as part of graduate studies in the City and Regional Planning Department and was supported by an Environmental Health Research Training Grant from the Public Health Service to the Harvard School of Public Health. This report emphasizes the computer mapping aspects of the work. A more complete presentation of the research and the methodology can be found in the masters thesis entitled, "Regional Planning and Air Pollution: Methodology and Case Studies."

The data used in the study was made available from many sources. The air quality data discussed in this report was provided by James Dallas and Cornelius O'Leary of the Air Use Management Program, Department of Public Health, Commonwealth of Massachusetts. The emissions data was provided by Gunthis Ozolins and the staff of the air quality and emissions data program, NAPCA.

John C. Goodrich, Editor
Cambridge, Massachusetts
April, 1970

REPORT J
BOSTON REGION STUDY

Table of Contents

PREFACE

1. INTRODUCTION

1.1. Methodology

1.1.1. The Air Pollution Cycle
1.1.2. Approaches to the Control of Air Pollution
1.1.3. Emphasis of the Research

1.2. Technical Considerations

1.2.1. Averaging Times
1.2.2. People and Activities
1.2.3. Control Regions

1.3. Control Agency Programs

2. DATA AND BASE MAPS

2.1. Data Considerations

2.1.1. Availability of Data
2.1.2. Manipulation of Data

2.2. Base Map Preparation

3. MAPPING AIR QUALITY AND EMISSIONS DATA

3.1. Suspended Particulates

3.2. Sulfur Dioxide

3.3. Emission Densities

REFERENCES

APPENDIX: COMPUTER GRAPHICS

List of Illustrations

Section 1. INTRODUCTION

Example

1-1 The Air Pollution Cycle

1-2 Dynamic Model of Cycle

Section 2. DATA AND BASE MAPS

Example

2-1 Flowchart of Data Averaging

APPENDIX: Computer Graphics

Figure

J-1 1966 Concentration of Suspended Particulates

- a. January
- b. February
- c. March

J-2 1966 Concentration of Suspended Particulates

- a. April
- b. May
- c. June

J-3 1966 Concentration of Suspended Particulates

- a. July
- b. August
- c. September

J-4 1966 Concentration of Suspended Particulates

- a. October
- b. November
- c. 11-month Average

J-5 1966 Concentration of SO_2

- a. January
- b. February
- c. Average of a. and b. (Winter)

J-6 1966 Concentration of SO_2

a. April
b. May
c. Average of a. and b. (Spring)

J-7 1966 Concentration of SO_2

a. July
b. August
c. Average of a. and b. (Summer)

J-8 1966 Concentration of SO_2

a. October
b. November
c. Average of a. and b. (Fall)

J-9 1966 Concentration of SO_2

a. Episode Period -- November 21, 1966
b. Episode Period -- November 24, 1966
c. January-November (11-month) Average

J-10 Development of Emission Inventory

a. Population Density by Towns
b. SOx Emissions, Average Day
c. Suspended Particulate Emissions -- Average Day

1. INTRODUCTION

The fields of public health and planning are quite diverse in their approaches to a problem. This diversity is an example of the differing approaches between the natural and the social sciences. The former focuses on a rational and meticulous approach--developing hypotheses and gathering data to test them. The latter is more concerned with a broad and comprehensive overview--relating many aspects of the environment to each other, using data from one situation to explain another, and setting policy in the absence of empirical findings.

The planning process is faced with the task of making decisions about the future with little knowledge of the present relationships that exist in the environment and few, if any, reliable indicators of the future relationships. To apply this process to a problem in the public health field naturally causes some consternation. However, the questions and problems concerning air pollution appear to be well suited to the combined approach of these two disciplines.[1]

There is an immediate need for decisions concerning control policy, jurisdictional area, standards of air quality, emission control regulations, and implementation plans, prompted in part by the Air Quality Act of 1967.[2] Information about air pollutant emissions, present air quality, and the effects of air pollution on people and their environment is needed. It is necessary to make projections of future emissions and air quality to determine policies for air quality control regions. Only a small portion of this information is presently available; much of it will not be available in the foreseeable future.

1.1 METHODOLOGY

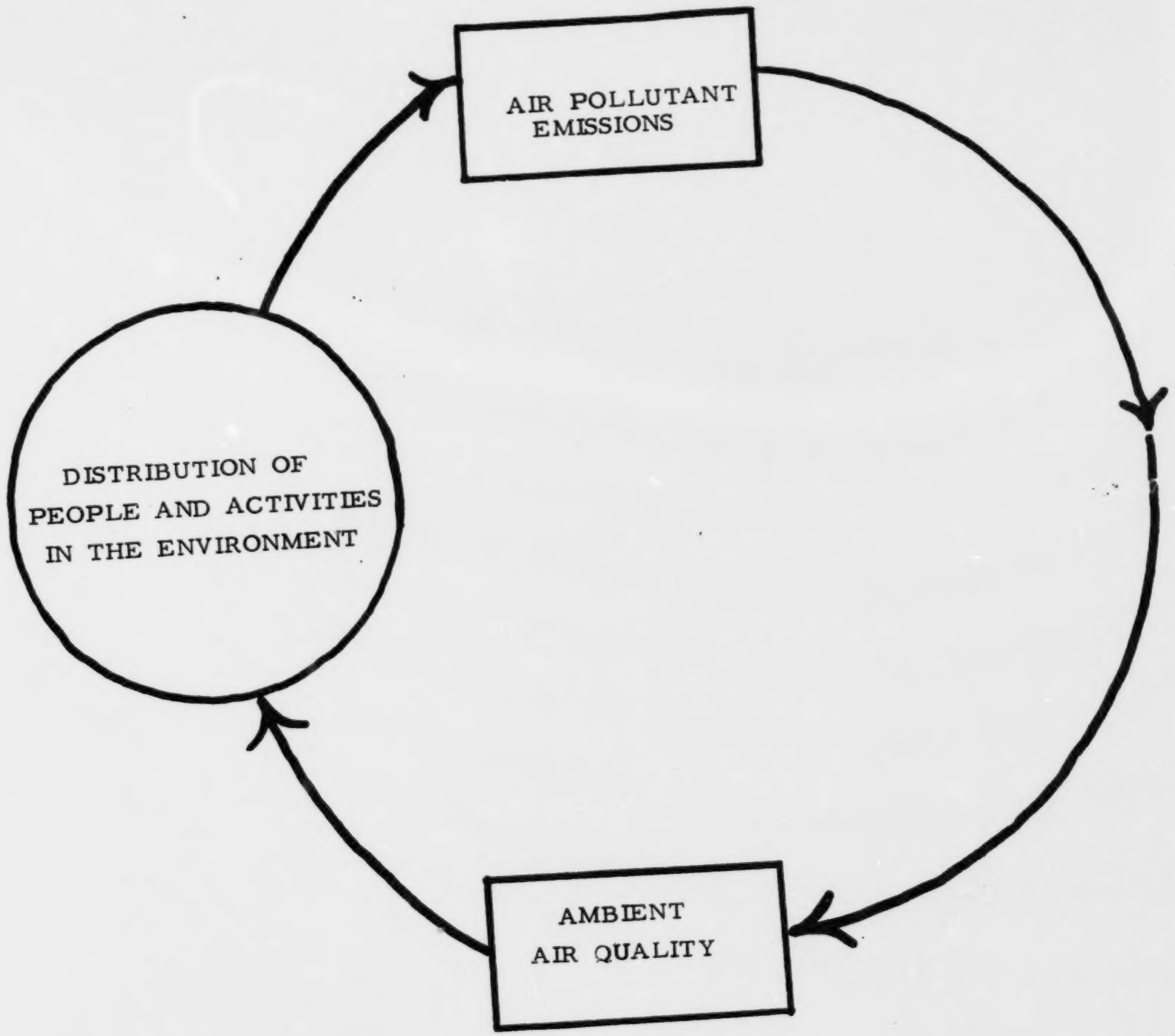
The aim of the research was to develop an internally consistent methodology for examining and predicting air pollutant emissions and air quality, using available socio-economic data and relationships. Socio-economic data can be used to develop an emission inventory, to provide an index of air quality on a regional scale, and to show the spatial distribution and extent of the population groups and activities affected by air pollution. This data can also be used for projections of future levels of emissions and air quality.

The patterns of pollution for alternative distributions of people and activities can be developed and compared as part of a control agency program. Logical divisions between control regions--and the primary areas of concern within a control agency's region--can be determined without a lengthy and costly data gathering process.

1.1.1. The Air Pollution Cycle

The first step in developing such a methodology is the identification of the components of the problem and the manner in which they interact with each other.

Man's activities--and especially the spatial and temporal distribution of these activities--produce dynamic patterns of air pollutant emissions. The concentrations of air pollution that result from these emissions, acted upon by the local meteorological and climatological conditions, increasingly affect man and his environment. This cycle is shown in Example 1-1.



Example 1-1
Air Pollution Cycle

To understand, and thereby have an affect upon, this cycle we need to know:

(i) how the distribution of people and activities produces air pollutant emissions;

(ii) how the pollutants emitted are acted upon, transported, and deposited so as to produce the measured concentrations of air pollution;

(iii) how various concentrations of air pollution affect people and activities;

(iv) how we can influence or control the emissions and emission-producing processes so as to lessen the effect of air pollution; and,

(v) how all of these change over time.

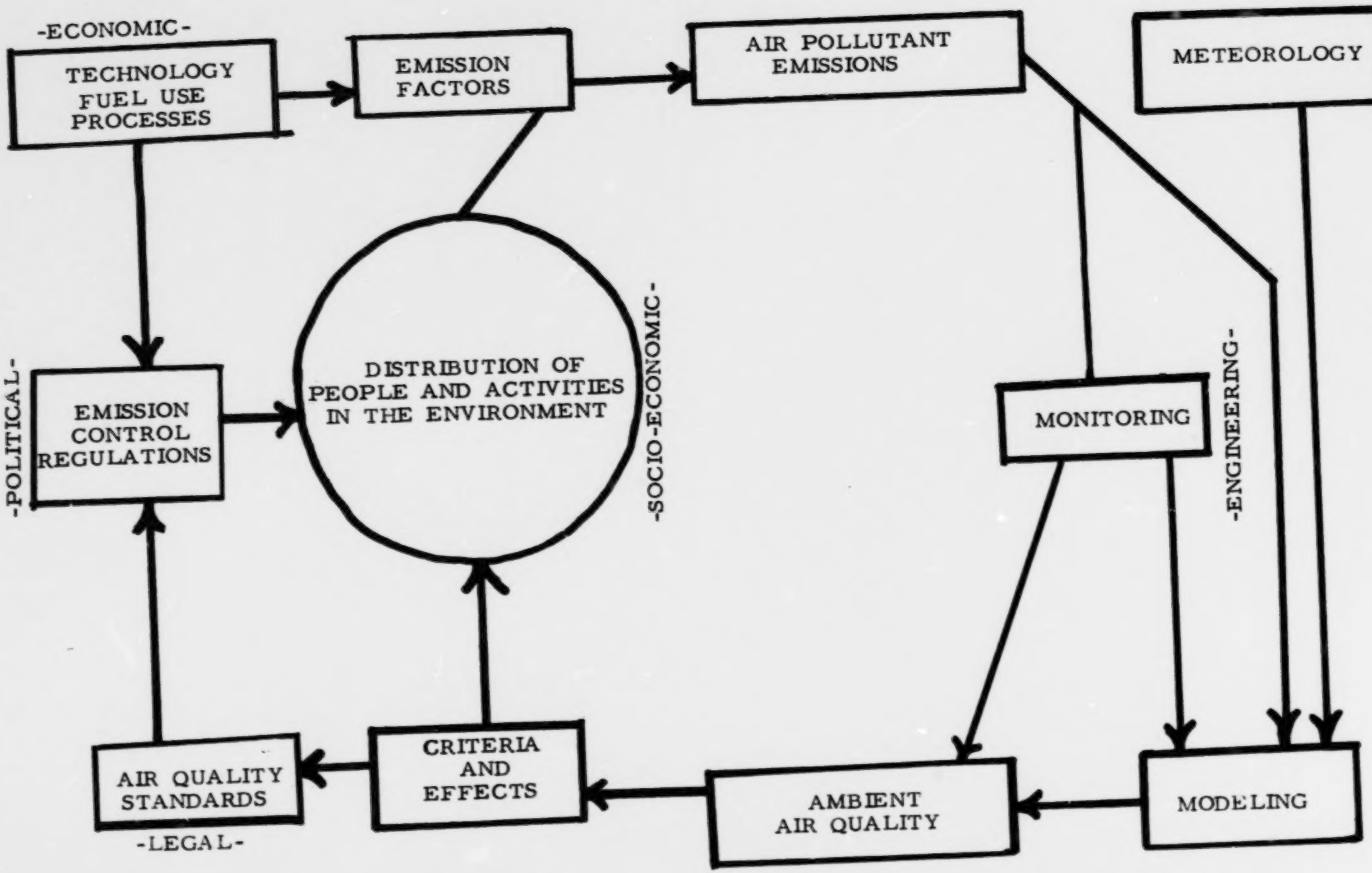
Example 1-2 shows a dynamic model for examining these questions.

1.1.2. Approaches to the Control of Air Pollution

This cycle of air pollution will continue to produce higher levels of ambient air quality unless the emissions are controlled. Emissions can be lessened by:

(i) Control of emissions at the source, based on regulations of air pollution control agencies, or,

(ii) Changes in fuel type and characteristics, such as the increased use of natural gas or nuclear energy in metropolitan areas.



Example 1-2
Dynamic Model of Cycle

These two approaches involve varying the strength of emissions at the source so as to achieve the desired levels of air quality. The first approach involves a careful cost-benefit analysis of control devices, particularly improvement in public health and other community benefits that would result. The second approach is concerned more with the technology of fuels--improved extracting, transportation, and desulfurization practices--the trade-off between more expensive but cleaner fuels, and the commensurate benefits derived from improved community air quality.

A third, and longer range, approach is possible. This involves the future development of population areas so as to minimize the levels of air pollution. Population and industrial areas can be located so that new polluters would not affect existing residential areas and new residential areas would not be affected by existing polluters. Alternative development schemes can be proposed and tested for their affect on air quality. First, changes or updates in the emissions inventory are projected. The updated inventory is then run through the diffusion model to generate new patterns of air quality. The plans can be evaluated and the best plan chosen according to the predicted levels of air quality.

1.1.3. Emphasis of the Research

The research concentrated on the inventorying and projecting of air pollutant emissions, the analysis of monitored air quality, the modeling of air quality, and the comparison of monitored and modeled data.[3]

One of the most important aspects of the research was the theoretical modeling of air quality utilizing a diffusion, or dispersion, model.[4] The inputs to such a model are source emission and meteorological parameters.[5] The output is the concentration of the pollutant under consideration at various points. It is generally calculated at ground level since we are concerned with the effects on people and their environment.

The study area was to have been all of Southern New England; however, it was decided to concentrate the majority of the analysis on the Boston region for a number of reasons. First of all, emissions data existed only for the Boston Region, for the Hartford-Springfield Air Quality Control Region, and for the State of Connecticut as a whole.[6] None of this data was detailed enough to provide reliable estimates of air quality utilizing a diffusion model. Secondly, the state of the art of diffusion modeling is not very advanced. To test the reliability of a model measured air quality data is needed for comparison. Only the Boston area provided the necessary air quality data and the possibility of developing a reasonable emission inventory.

The diffusion model was to have been run for sulfur dioxide (SO_2). Preliminary investigation revealed that air quality data for SO_2 was not as readily available as data for suspended particulates.[7] Furthermore, recent findings have pointed out that both sulfur oxides and suspended particulates should be used as an index of air quality, although health criteria used to deal mainly with sulfur oxides as the best overall index.[8] Therefore, the research was carried forward primarily for suspended particulates.

1.2. TECHNICAL CONSIDERATIONS

The product of research relating regional planning to public health should unquestionably be the effects of man's pollution, both on himself and his environment, and a projection of these effects into the future. To analyze the effects and to examine the relevant control policies, we need to have an understanding of several technical and public health considerations.

1.2.1. Averaging Times

First among these is the averaging time used for a particular pollutant and its relevancy to health standards.[9] We are interested in:

(i) the acute or air pollution episode case--implying an averaging time of perhaps five minutes, or one hour; and,

(ii) the chronic or long-term effects on the individual or community-implying averaging times of a year or more, or perhaps an average over a lifetime.

Analyzing the data for different averaging times is quite difficult since the measured data is gathered for specific periods.[10] However, we can choose the time period over which we average this measured data. We can examine particular 2-hour, 4-hour or 24-hour readings, or average all of the readings for a month, season, year, or period of years.

In general, the longer the time period, the less (i) the variability and dispersion of the data, (ii) the effects of maximum and minimum values, and (iii) the influence of changing meteorological conditions.

1.2.2. People and Activities

The second consideration is the setting of air quality standards in terms of the population or activities that are the most affected. We must decide whether we want standards of air quality which protect all people all of the time (i.e., so that no one is ever subjected to a one-hour level above a certain amount), 90% of the people all of the time, all of the people 90% of the time, and so on. Likewise, we must concern ourselves with the levels of air quality that affect the average person, as opposed to levels that adversely affect certain susceptible groups or other aspects of our environment, such as vegetation, metals, paints, or clothing.

The "criteria" that relate particular air quality levels to affects on people and their environment have only been loosely spelled out. They have not been translated into a concise set of operating standards which would give us precise levels of pollution--for various averaging times--which should not be exceeded.[11]

1.2.3. Control Regions

The third consideration is the jurisdictional area over which standards should be set and control programs exercised. A standard for air quality set for an urban residential area is not necessarily of equal validity in a very rural area where there are few people or activities.

When we attempt to translate desired air quality standards into emission control regulations, the problem is compounded. An area with one set of emissions and

climatology may generate the same levels of air pollution as another area with a completely different mix of emissions and climatology. Lowering the levels of air pollution in each case--in terms of ground level concentrations--to some regional standard may imply completely different emission standards, reflecting the particular composition of emissions, emitters, and climatology.

1.3. CONTROL AGENCY PROGRAMS

In theory, the overall approach should be of interest to an air pollution control agency. However, much more data gathering and analysis is necessary to develop the methodology into a set of working tools. In practice, one of the most useful aspects of the methodology is the analysis and mapping of air quality and related data.

Mapping of existing levels of air quality for a region or metropolitan area can show:

(i) which areas have pollution exceeding a certain standard, and thereby form a logical control region, or

(ii) given a jurisdiction for control, which areas within this jurisdiction exceed the standards. Projections can be made of future levels of pollution--with and without the implementing of emission controls--and the areas which will exceed the standards delineated.[12]

First, air quality data must be analyzed and mapped for various averaging times. Daily, monthly, seasonal, and yearly averages can be determined, depending upon the original data.

For example, daily levels of air quality monitored for a whole year may be useful if displayed as:

(i) an arithmetic mean for the year,

(ii) a geometric mean for the year, or

(iii) an average for a month or a season.

The data may also be presented so as to show the levels of air quality exceeded 50% of the days or 1% of the days. With such a spectrum of averaging times, it is possible for an agency to relate present and projected air quality to the pertinent criteria and standards.

We can examine the question of who is affected by what levels of air pollution. We might wish to set a standard so that all areas and all people were subjected to pollution above a certain level no more than 1% of the days in the year. The time-averaging case depicting the 99th frequency percentile would thus be valuable.[13]

A particular interest in critical or episode periods would prompt us to take a closer look at what levels are attained during such periods. Such an interest would exist with a control policy aimed at rapidly shutting down emitters.[14]

Finally, we can correlate levels of air quality with socio-economic variables to determine what segments of the population, and in what parts of the region, are affected.[15]

2. DATA AND BASE MAPS

Considerable effort was devoted to the preparation of data banks and base maps. Generally, air quality data has not been gathered and stored in a computer form with mapping--either computer or otherwise--in mind; it is often necessary to manipulate the data so that variables can be related to their corresponding spatial locations. In many cases there may be an insufficient number of data points to produce meaningful maps of a region.

For a project of this magnitude, it is advisable to produce computer base maps of sufficient detail and flexibility so as to handle all forseeable types of data that may be used. This includes air quality, emission, and related socio-economic data. The desire to be able to produce maps at varying scales and for selected parts of the region further necessitated detail in the preparation of the base maps.

2.1 DATA CONSIDERATIONS

2.1.1. Availability of Data

The Boston region was chosen as an area for study particularly because of the availability of data. A special study which monitored the air quality was conducted in 1966; this included data for sulfur dioxide and suspended particulates[16]. An emissions inventory was conducted in 1967 for the entire region. It was thus possible to analyze and map both air quality and emissions data, and to model air quality based on the 1967 emissions data. The modeled air quality data could then be compared with the monitored air quality data.[17]

The air quality data for sulfur dioxide included four-hour readings over an eleven month period, taken at ten sampling stations. It was necessary to time-average this data for days, months, seasons, and an 11-month year; in addition the data had to be related to spatial locations. Similarily, the suspended particulates data was measured for 24-hour periods over the same eleven month period at twenty sampling stations. Monthly, seasonal, and yearly averages were determined for mapping.

The emissions inventory data was not available in computer form. This data from the 1967 Federal inventory was broken down into two categories: (i) major point sources, and, (ii) area source data aggregated into 61 square zones, or grid cells. For each of these area zones data was presented on emissions for the average summer day, average winter day, and average annual day. Only the area source data was mapped in this study.

2.1.2. Manipulation of Data

Two types of data manipulation may be necessary in air pollution studies. The first type involves the data handling necessary to produce the appropriate time-averaging of the data. The second type involves the creation of a data bank compatible with the computer mapping program. Generally, a simple program can be written to manipulate the data bank so that all variables to be mapped can be matched with their corresponding data point locations as required by the SYMAP program.

Considerable time was spend on data handling programs for the time averaging of the air quality data. This involved taking the 4-hour (in the case of SO_2) or the 24-hour (in the

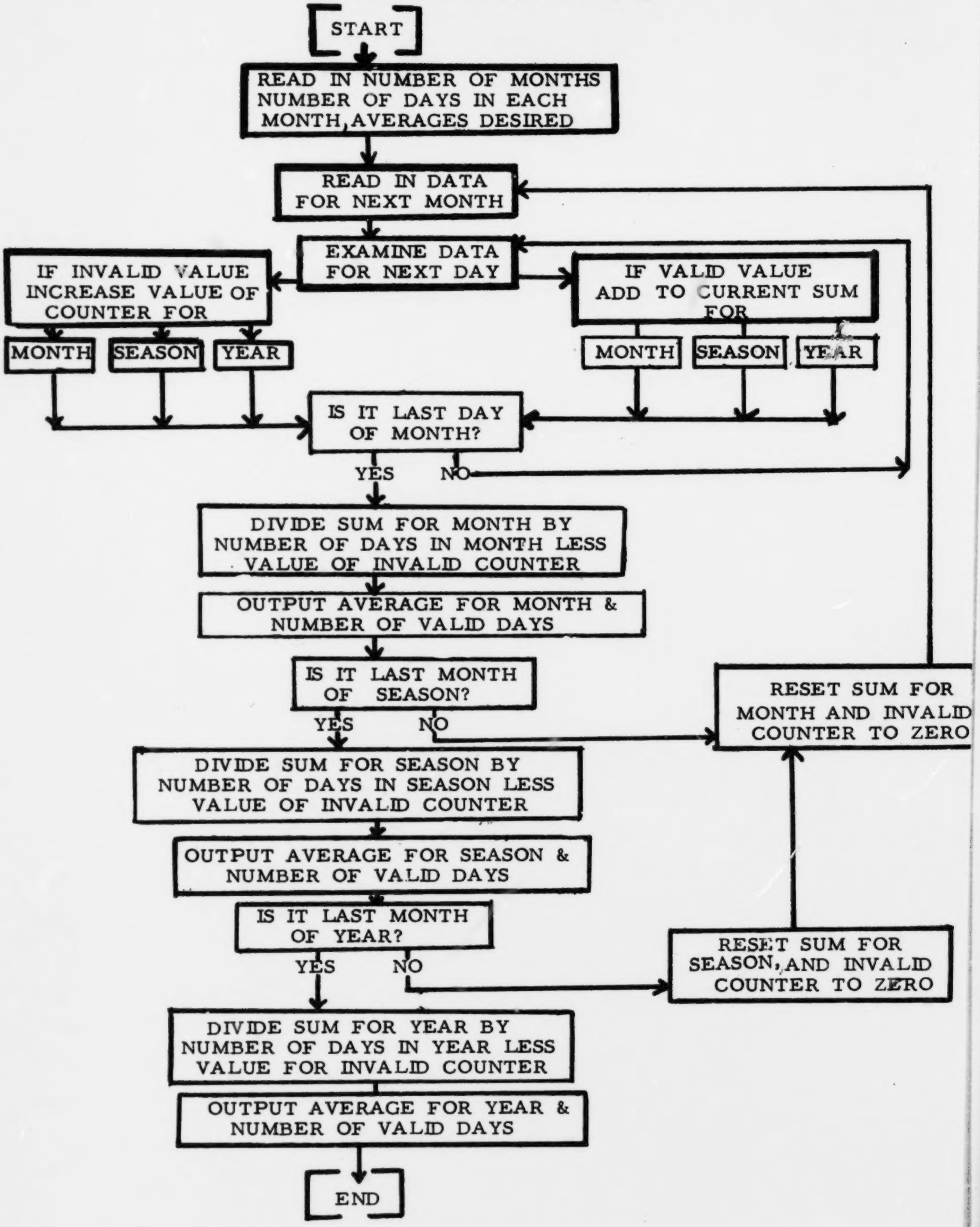
case of suspended particulates) readings and producing daily, monthly, seasonal and yearly (11 month) averages. Example 2-1 shows a flow chart of such a data averaging program.

A general program to do any number of time-averagings from the same data bank was written. The original data bank was structured by the time periods for which the data was measured. For any one time period--such as a 4-hour reading--the values at all stations were recorded on one record. After the data had been time-averaged to produce a monthly average, the values for all the stations would still be on the same record. It was then necessary to use the second set of data handling programs to create a data bank which contained, on one record, the values for all time periods for any one location or station.

Both the Federal and State emission inventories were done by using approximating techniques. These techniques follow a prescribed methodology and use national or standard emission factors[18]. For point sources--such as power plants--emission factors are applied to the fuels used, supplemented by information such as the percent of heat for process and daily and seasonal variations in fuel use. For area sources--such as space heating--population density, per household fuel consumption, and type of fuel are used as the base parameters. It was found that the state emission inventory--although on a more detailed grid basis than the Federal--was far less complete. However, the Federal inventory though complete aggregated data by uniform processes into large grid cells based mainly on population distribution and control totals of fuel use for the entire region. Point sources were handled separately.[19]

Starting with this relatively crude Federal inventory numerous data banks were utilized and emission factors developed

Flowchart of Data Averaging


START
READ IN NUMBER OF MONTHS NUMBER OF DAYS IN EACH MONTH, AVERAGES DESIRED
READ IN DATA FOR NEXT MONTH
EXAMINE DATA FOR NEXT DAY
IF INVALID VALUE INCREASE VALUE OF COUNTER FOR
MONTH
SEASON
YEAR
IF VALID VALUE ADD TO CURRENT SUM FOR
MONTH
SEASON
YEAR
IS IT LAST DAY OF MONTH?
YES
NO
DIVIDE SUM FOR MONTH BY NUMBER OF DAYS IN MONTH LESS VALUE OF INVALID COUNTER
OUTPUT AVERAGE FOR MONTH & NUMBER OF VALID DAYS
IS IT LAST MONTH OF SEASON?
YES
NO
RESET SUM FOR MONTH AND INVALID COUNTER TO ZERO
DIVIDE SUM FOR SEASON BY NUMBER OF DAYS IN SEASON LESS VALUE OF INVALID COUNTER
OUTPUT AVERAGE FOR SEASON & NUMBER OF VALID DAYS
IS IT LAST MONTH OF YEAR?
YES
NO
RESET SUM FOR SEASON, AND INVALID COUNTER TO ZERO
DIVIDE SUM FOR YEAR BY NUMBER OF DAYS IN YEAR LESS VALUE FOR INVALID COUNTER
OUTPUT AVERAGE FOR YEAR & NUMBER OF VALID DAYS
END

Example 2-1
Cont'd

Notes:

The illustration is for the data from only one monitoring station; for several stations--depending upon the form of the data--we would run through the steps once for each station, or use subscripted variables and process all stations at once.

The illustration is for a sample case: determining monthly, seasonal, and yearly arithmetic means from daily data for a pollutant such as suspended particulates. The same concepts hold for geometric means or for averages for different time periods; for instance, one can average all the week days, all the weekends, all the days with a northwest wind, etc. for purposes of statistical comparison with emissions or meteorological data or modeled air quality.

so as to generate a much more detailed inventory for the central part of the Boston Region. Allocations were made from large emission zones, to cities, to census tracts, and finally to a 5000 foot grid. The known variable throughout was space heating. Most of the other categories were known by town, with the exception of the process heat, commercial, and automobile categories. These were apportioned based on the known data and subjective planning criteria. Total emissions were allocated from towns to tracts and then to the grid based on the space heating emissions. Preliminary investigation shows that this technique produces a much more useful inventory of emissions. Future projections of dwelling units and employment for 1968, 1971 and 1974 were used to update this inventory and to examine the methodology of projecting air quality with a variable inventory and flexible diffusion model.

Although quite sophisticated data handing and manipulating routines were developed for use with the emissions inventory, they depended upon data that was not fully available at the time of the study. Therefore, the procedures were not carried out with the degree of detail desired. No maps of this detailed inventory are presented in this report.

2.2. BASE MAP PREPARATION

A very detailed and sophisticated base map of the Boston Region was prepared as a part of this study. It encompassed an area of some 76 towns--the Standard Metropolitan Statistical Area (SMSA)--and included the entire region for which air quality and emissions data were available. The base map was designed to handle air quality, emissions, and related socio-economic data as part of the same system. This posed several problems.

First of all, the coordinate system associated with each of these types of data varies. The air quality data is related to the State Plane Coordinate (SPC) system; the Federal emissions data is related to the Universal Transverse Mercator (UTM) system. It was therefore necessary to incorporate a routine into the program to convert from one coordinate system to another. Secondly, for various applications in the project different scales of mapping or sub areas of the study area were desired. For the air quality data only an area comprising the inner 20 or so towns was desired because air quality data had not been measured outside this region. However, for the Federal emissions inventory, data had been gathered for the entire 76 town region. The base map preparation had to take into account the desire to work at these different scales and to map various portions of the study area.(20)

The SYMAP program has five basic data packages. These refer to the outlines, data points, legends, values, and map electives. The first three of these packages can be thought of as pertaining to the base map: they generally remain the same for all maps in a series. The values package is the data bank used for the study. With the aid of the user subroutine a particular variable can be selected from this data bank for each map. The map electives package is used to specify the title of the map and any electives such as size, extent of the area to be mapped, and symbolism or levels to be used.

The outline package is used to specify the boundaries of the study area. In the case of the Boston Region the boundaries specified were the ocean to the east and the borders of the towns within the SMSA to the north, south, and west. This outline is approximated by straight line segments connecting

vertices; the x and y coordinates of these vertices are used to define the outline. The coordinates for the outline, data points and legends were generally specified in terms of the State Plane Coordinate System since this had been used by the state and local air pollution agencies for their data.[21] The outline was coded in sufficient detail so that small portions of the study area could be selected out, blown up and still exhibit significant detail when mapped.

Several data point packages were required for this study. Separate packages had to be prepared for the sulfur dioxide and suspended particulates air quality data and for the area source emissions data. In each case this required coding the x and y coordinates of the data locations. For the air quality data this was the location of the monitoring stations; for the emissions data it was the location of the centroid of the grid cells used. The air quality data was recorded in terms of the SPC systems; however, the emissions data was available only in terms of the UTM system. It was therefore necessary to use the subroutine to transform the data points from one coordinate system to the other when emissions data were being mapped.

Legends are coded in the same manner as outlines or data points. The legends included: areas, such as the lakes shown on the maps; lines, such as rivers or municipal boundaries; points such as landmarks, and, any explanatory text legends that appear on the map. Since great detail was used to define all of these legends it is possible to enlarge portions of the study area and still show the rivers, lakes and other legend features of the study area.

3. MAPPING AIR QUALITY AND EMISSIONS DATA

Over fifty maps of air quality were produced as a part of this study. These included maps of sulfur dioxide and suspended particulates for each of the eleven months, four seasons, and for the annual mean. In addition maps of the annual geometric mean were made.

During 1966 a particularly severe air pollution episode occured in the Northeastern United States around Thanksgiving time.[22] A set of maps showing daily levels of sulfur dioxide and suspended particulates was run for the period November 21 through November 25. No other maps of daily levels of air quality were run nor were any maps made showing 4-hour levels of sulfur dioxide.[23]

For the Federal emission inventory maps of the average annual day, average summer day, and average winter day were produced for suspended particulates, sulfur dioxides, and several other pollutants. This set of maps was run for the entire base map area comprising the 76 towns of the Standard Metropolitan Statistical Area (SMSA). The air quality maps were run for only the 20 town region in the center of the Boston area. A representative set of these maps is included in the Appendix on Computer Graphics and is described briefly in the following sections.

3.1. SUSPENDED PARTICULATES

Figures J-1 through J-4 show the monthly averages for suspended particulates for January through November and the 11-month or annual average for 1966. The data for these maps were derived from daily or 24 hour readings. When we examine

these maps we find a fair amount of variation in the series, both spatially and temporally, In general, the highest concentrations are in the center of the region in the vicinity of downtown Boston; this would be expected from the general concentration of pollution-generating activity in the center of the region.

A consistent set of symbolism was used throughout this set of maps; therefore, levels are comparable from one map to another. We find that the 'lightest' month is September and the 'darkest' is February. For the month of May there are three peaks in the center of the area, rather than one main peak as we find in most of the other months and in the 11-month average. As might be expected, the 11-month average exhibits a fair degree of concentricity, whereas some of the individual months do not display this characteristic.

Without examining the data in detail it would be quite difficult to draw any conclusions from this set of maps. They are useful for understanding general trends over time and over the portion of the region mapped.

3.2. SULFUR DIOXIDE

Figures J-5 through J-8 show the monthly averages for sulfur dioxide for a number of the months monitored in 1966. In addition, the two-month seasonal averages are shown for this time period.[24] Looking at Figure J-5 we find that the month of January exhibits a predominant wind; in the seasonal average January is overshadowed by the February pattern. The same is true with the Spring average: the concentricity of the May air quality levels is quite apparent in the spring average. The levels

found in the summer months are quite low and without much variation. For this particular year there was a great deal of variability and some very high readings for the month of November, particularly during the episode period. This is reflected in the seasonal average as well. It is interesting to note that the basic patterns for both October and November are similar.

Figure J-9 shows the daily readings for the first and the fourth days of the Thanksgiving Episode period. It is apparent that the air quality has built up to quite high levels by the fourth day; on the fifth day the levels began to subside. The final illustration in Figure J-9 shows the 11-month average for sulfur dioxide. Here we see what affect the time averaging of data can have, particularly in terms of the smoothness of the surface. This surface is composed of nearly concentric circles and is in great contrast to the daily averages shown in the same illustration.

In the daily maps shown in Figure J-9 it should be pointed out that as we approach the borders of the map we have less and less information that is reliable. This is because of the interpolation algorithm of the program.[25] At the corners of the map the program is apt to have fewer reliable data point locations to use in interpolating the values for mapping. The more the data is averaged, as in the annual case, the less these spatial variations and inaccuracies are apparent.

3.3. EMISSION DENSITIES

Figure J-10 shows the average annual emission density for suspended particulates and sulfur dioxide according to the 1967 Federal inventory. The third illustration shows the 1965 population density, based on population by towns.[26] If we compare the

average emission densities from the inventory with the 1965 population density by towns, we find a very revealing similarity. Two statements can be made about this similarity. First it tends to substantiate the contention that the Rapid Survey Technique of emission inventorying is crude in its reliance upon population distribution as the main indicator of emissions. Second, and conversely, if we are in need of a crude representation of emissions on short notice for a control agency program, we can use population density as a first approximation. Of interest for planning as well as for air pollution control is the excellent manner in which route 128 follows the contour of 2500 people per square mile, except in the slowest growth area in the region, the southwest sector. There are quantifiable emission densities which correspond to this level of population density.

REFERENCES

(1) Air pollution is a relatively new area of study in the public health field. The data available is scanty and one is therefore forced to make 'best estimates' --a task the planner is accustomed to doing. In addition trends and future situations must be examined, laws and regulations determined, and choices made between alternative control strategies. The author comes from a civil engineering background and was studying both planning and public health when this work was undertaken, although the major emphasis was on a planning approach and methodology. The full work is discussed in the thesis "Regional Planning and Air Pollution Control: Methodology and Case Studies", submitted in partial fulfillment of the requirements for the degree, Master in Regional Planning, May 1969. The majority of the research was made possible by a Public Health Service Environmental Health Research Training Grant administered through the Harvard School of Public Health, September 1967 to May 1969.

(2) U.S. Public Law 90-148, "Air Quality Act of 1967", 90th Congress, S. 780, (November 21, 1967).

(3) Only the present emission inventory and monitored air quality are presented here. Most of the emission inventory projection was done for southern New England as a whole, due to data availability. The modeled air quality data was incomplete and therefore not mapped. See Volume Two, Report C for a discussion of modeled air quality and Report F for comparison of monitored and modeled data.

(4) Modifications were mad e to the NAPCA difiusion model, written by Delance O. Martin and Joseph A. Tikvart. There are several adaptations of this model (principally, that by T.R.W., Inc.) and other similar models, all based on the same generalized diffusion equation. The original model had no provision for a decay function or adjusting of the mixing depth and emissions based on the time of year. These were all added to the new model, as well as sophisticated data handling, storage, and retrieval techniques to consider several meteorological cases and updatings in the emission inventory at once.

(5) these include stack height and other source-related factors, frequencies of wind speed, direction and stability class and the depth of the mixing layer.

(6) --Commonwealth of Massachusetts, Department of Public Health, Division of Air Resource Management, Boston Region Total Emissions, by Category, Zone, Towns, 1966 Selected Process Emission factors; Census Tract Data (41 Town Boston Region) for 1960 Population, Homes Using Exact Type of Fuel, Overlay to Proportion Census Tract Data to 5000 Foot Grid Cells (in computer useable form); Fuel Use Data From Questionnaire, 1965-1966, 1700 Respondents (in computer useable form).

--U.S. Department of Health, Education and Welfare, Public Health Service, National Air Pollution Control Administration, "Report for Consultation on the Metropolitan Boston Intrastate Air Quality Control Region"; also, "Report for Consultation on the Hartford-Springfield Interstate Air Quality Control Region".

--U S. Department of Health, Education and Welfare, Public Health Service, National Air Pollution Control Administration, "Air Pollutant Emission Survey for the Boston Standard Metropolitan Statistical Area", Durham, North Carolina (August 1968).

--Air Quality and Emission Data Program, Durham, North Carolina, Boston Region, Area and Point Source Fuel Uses, Emissions, and Socio-Economic Data; Hartford-Springfield Region, Area and Point Source Fuel Uses, Emissions, and Socio-Economic Data.

--Office of Regional Activities, Emission Inputs and Air Quality Outputs for T.R.W., Inc. Diffusion Model for Boston Air Quality Control Region.

(7) --Commonwealth of Massachusetts, Department of Public Health, Division of Air Resource Management. 4 - Hour SO_2 and 24 - Hour Suspended Particulates Data, January-November 1966 (in computer useable form); Air Quality Sampling Data (Average Suspended Particulates), Various Years for Worcester, Fitchburg, Springfield, Mansfield, Nantucket, Fall River, Northampton. 1966 Estimates of Air Quality for various locations.

--Connecticut Air Sampling Network, Suspended Particulates, 1966-1968, Connecticut State Department of Public Health.

--USPHS, National Air Sampling Network Data for 1966

(8) This is reflected in the most recent health criteria released by the Federal government;

also, see U.S. Department of Health, Education and Welfare, Public Health Service Bureau of Disease Prevention and Environment Control, National Center for Air Pollution Control, "Air Quality Criteria for Sulfur Oxides", Washington, D.C. (March 1967).

(9) for a discussion of this topic see the Kansas City Region Study Report, Volume Two, Report D.

(10) for SO_2 this is generally by 2-hour, 4-hour, or 24-hour periods, and for suspended particulates by 24-hour periods.

(11) The initial Federal criteria for sulfur oxides (March 1967 - See reference 8) did give certain recommended standards--principally in terms of annual geometric means--but the most recently published criteria for sulfur oxides and suspended particulates have stopped short of recommending standards.

(12) Volume Two, Report D on the Kansas City Region Study shows examples where areas above and below standard have been delineated--only two shadings are shown in these illustrations. The standards for the Boston area had not been set when this work was undertaken.

(13) See Volume Two, Report D for a discussion of time averaging data for various frequency percentiles.

(14) The State of New Jersey, in particular, has such a control policy; they need to spatially determine levels of air quality so as to declare episode conditions for all or parts of control regions.

(15) See Volume Two, Reports A and B on the St. Louis Region Study.

(16) --1966 Sulfur Dioxide data - 10 stations

Commonwealth of Massachusetts, Department of Public Health, Air Use Management Program, Bureau of Environmental Sanitation, "Special Report on the Investigation and Study of Air Quality in the Metropolitan (Boston) Air Pollution Control District, 1965-1966", Boston, Massachusetts (September 16, 1968).

Harvard School of Public Health, 4-Hour SO_2 Data, January-November 1966, From Division of Air Resource Management, Manipulated to Remove Invalid Data (in computer useable form).

--1966 Suspended Particulates data - 20 stations

Commonwealth of Massachusetts, Department of Public Health, Division of Air Resource Management, 24-hour suspended particulates data, January-November, 1966 (in computer useable form).

--1967 Emissions Inventory - area sources only - 61 zones.

U.S. Department of Health, Education and Welfare, Public Health Service, National Air Pollution Control Administration "Air Pollutant Emission Survey for the Boston Standard Metropolitan Statistical Area", Durham, North Carolina (August 1968) (in tabular form)

For the air quality data, SO_2 was gathered by 4-hour sequential samplers and particulates by 24-hour hi-vol samplers.

(17) only maps of air quality and emissions data were actually produced.

(18) U.S. Department of Health, Education and Welfare, Public Health Service, Division of Air Pollution Control, "Rapid Survey Technique for Estimating Community Air Pollution Emissions", Cincinnati, Ohio (October 1966).

(19) The federal emission inventory for the Boston S.M.S.A. utilized 20,000 foot and 40,000 foot grid cells for the area sources. Population data by towns was used as the base, allocating emissions uniformly to grid cells based on the portion of the town in a grid cell, the population, and control totals of total emissions for

the study area. The inadequacies of the inventory include the scale of aggregation into large grid cells, the use of allocation techniques based solely on population by towns and control totals of fuel use and emissions by categories for the entire S.M.S.A., and the uniform apportionment of emissions as follows: if 20% of the area of a town falls into a particular grid cell, then 20% of the emissions of that town are allocated to the grid cell. In deriving the emission densities from the inventory, the areas of grid cells on the border of the study region were adjusted by the author to take into account only that portion of the cell actually within the towns of the inventory.

(20) The user subroutine--see Volume Two, Report K--was used for translating axes, as from the UTM to the SPC System; however, electives in the map package were used for changing scales and selecting different portions of the study area for mapping. For the user changes in the map package are much easier than additions or changes to the user subroutine.

(21) The SYMAP program requires that there be no more than 100 vertices per outline 'island'; with several thousand points needed to define the outline several islands were necessary. See Volume Two, Report K for a more detailed discussion of this and the other packages.

(22) U.S. Department of Health, Education and Welfare, Public Health Service, "Thanksgiving 1966 Air Pollution Episode in the Eastern United States", PHS Pub. No. 999-AP-45, Durham, North Carolina (July 1968).

(23) Maps showing diurnal variations in Sulfur Dioxide were produced for the St. Louis Region Study; see Volume Two, Reports A and B.

(24) Two-month seasonal averages, as opposed to three month averages, were used for two reasons; data for only 11 months were available (a three month winter average could, therefore, not be determined) and the months of March, June, September, and December are often considered to be transitional in terms of climatology and therefore not representative.

(25) See Volume Two, Report L, for a discussion of the interpolation algorithm used in the SYMAP program.

(26) Data used for this map were obtained from a Data Bank of 1960 Census Information by Towns, 76 Town S.M.S.A. (in computer useable form). This included the 1965 population estimates from a state survey. This map required a new data points package, containing the centroid locations of the 76 towns.

APPENDIX

COMPUTER GRAPHICS

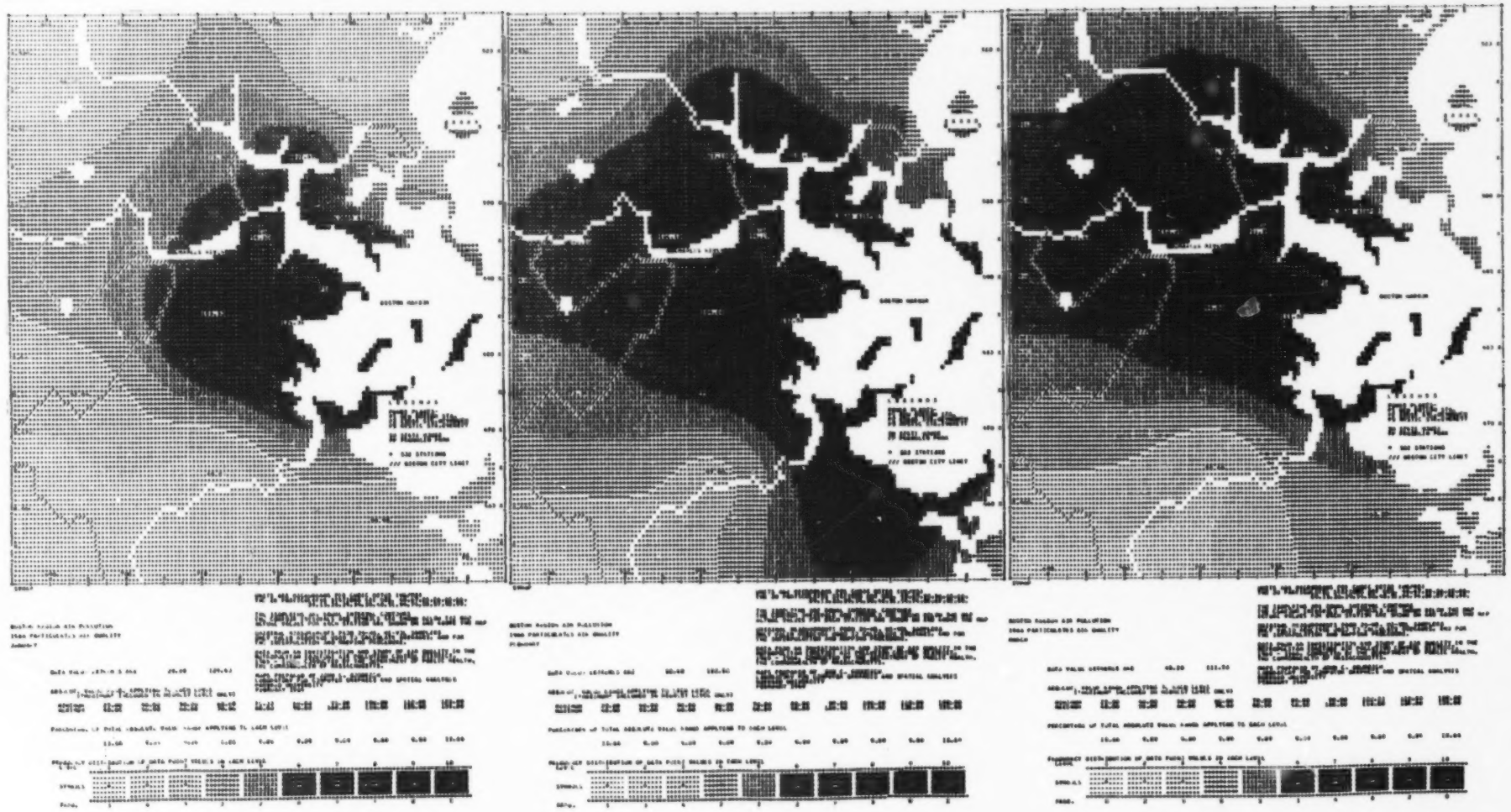


FIGURE J-1

BOSTON REGION STUDY
1966 Concentration of Suspended Particulates
a. January b. February c. March

Details of illustrations in this document may be better studied on microfiche

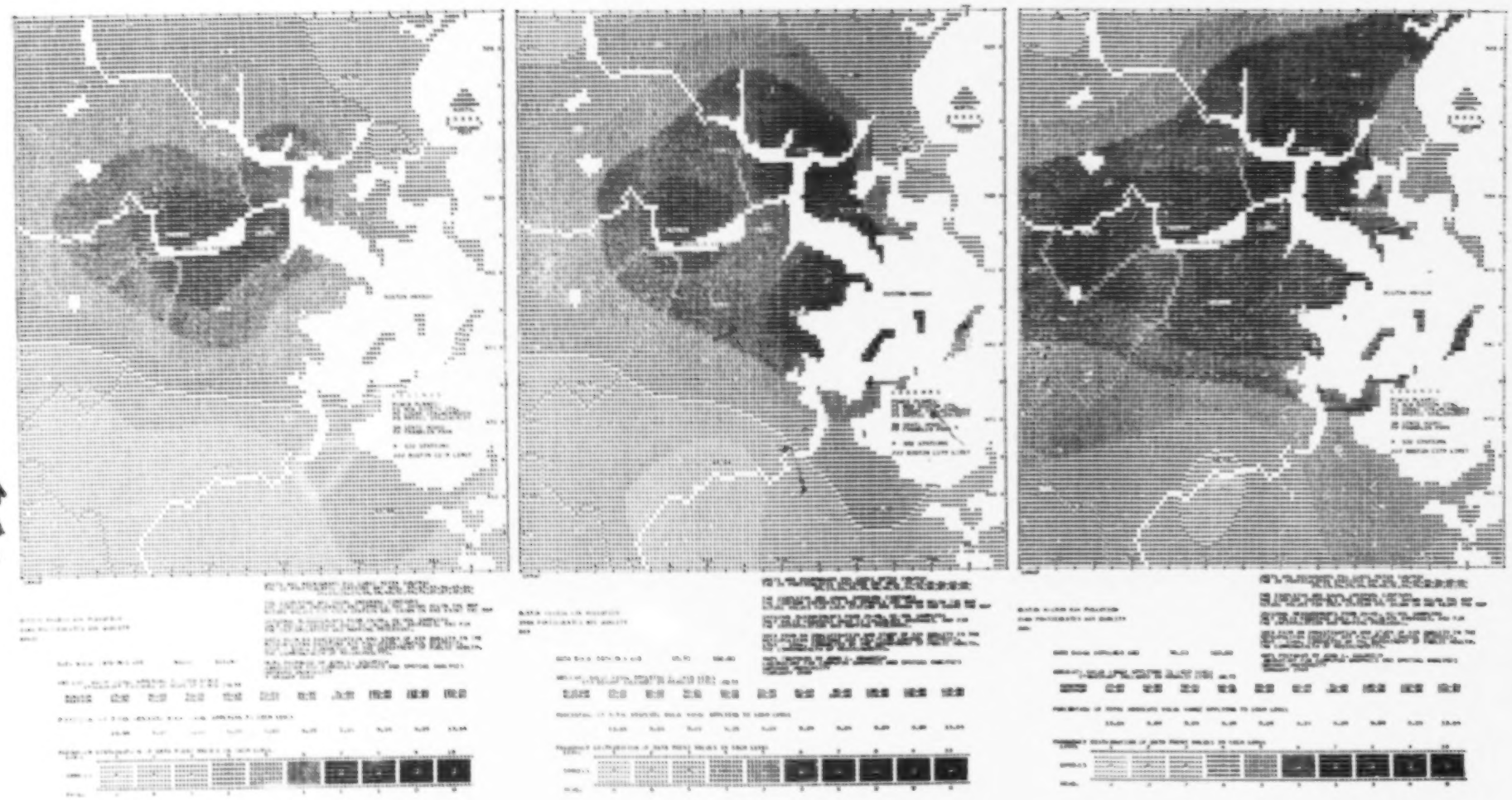


FIGURE J-2
BOSTON REGION STUDY
1966 Concentration of Suspended Particulates
a. April b. May c. June

Details of illustrations in this document may be difficult to read.

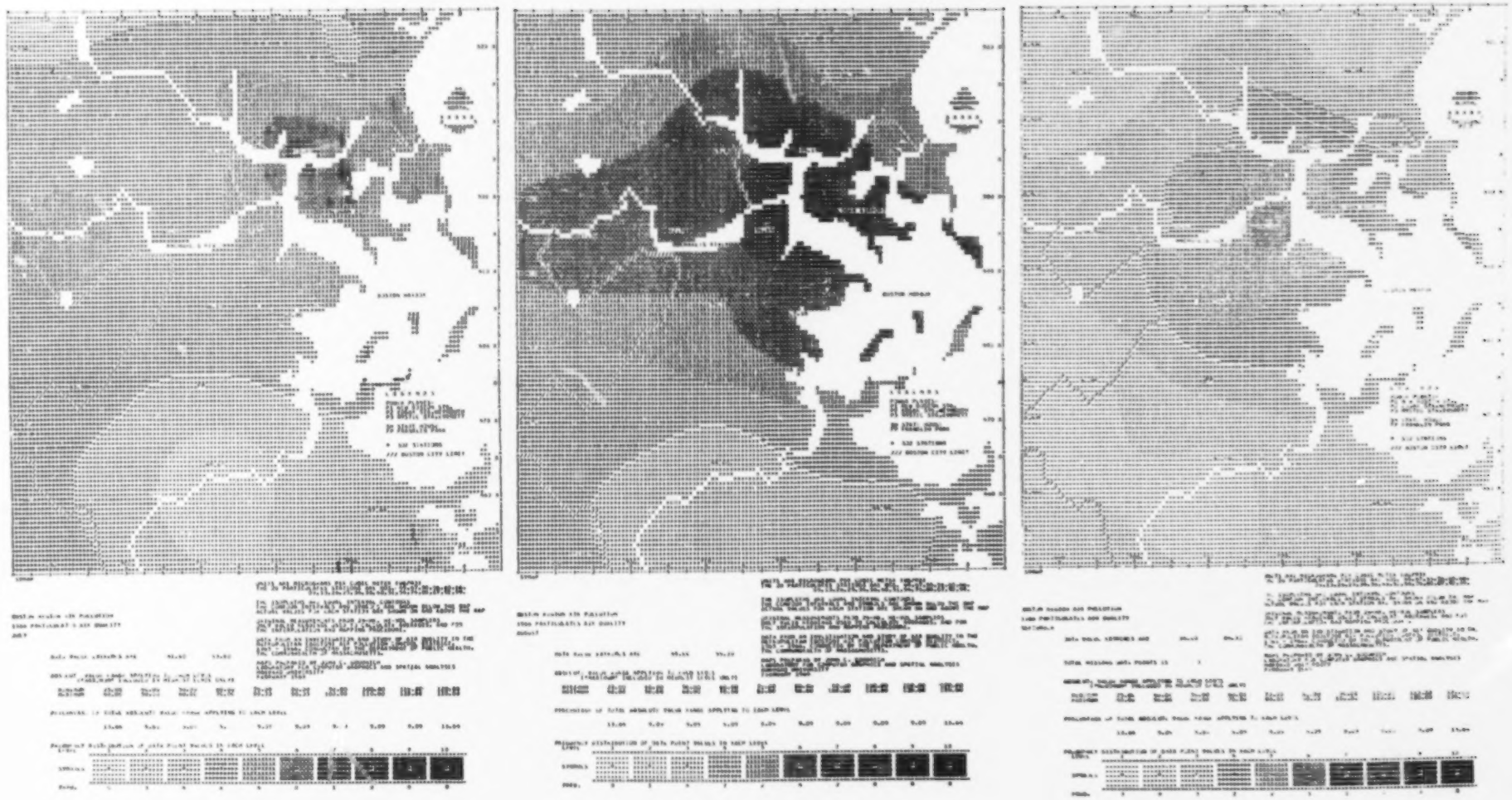


FIGURE J-3

BOSTON REGION STUDY
1966 Concentration of Suspended Particulates
a. July b. August c. September

Details of illustrations on this document may be better studied on microfiche

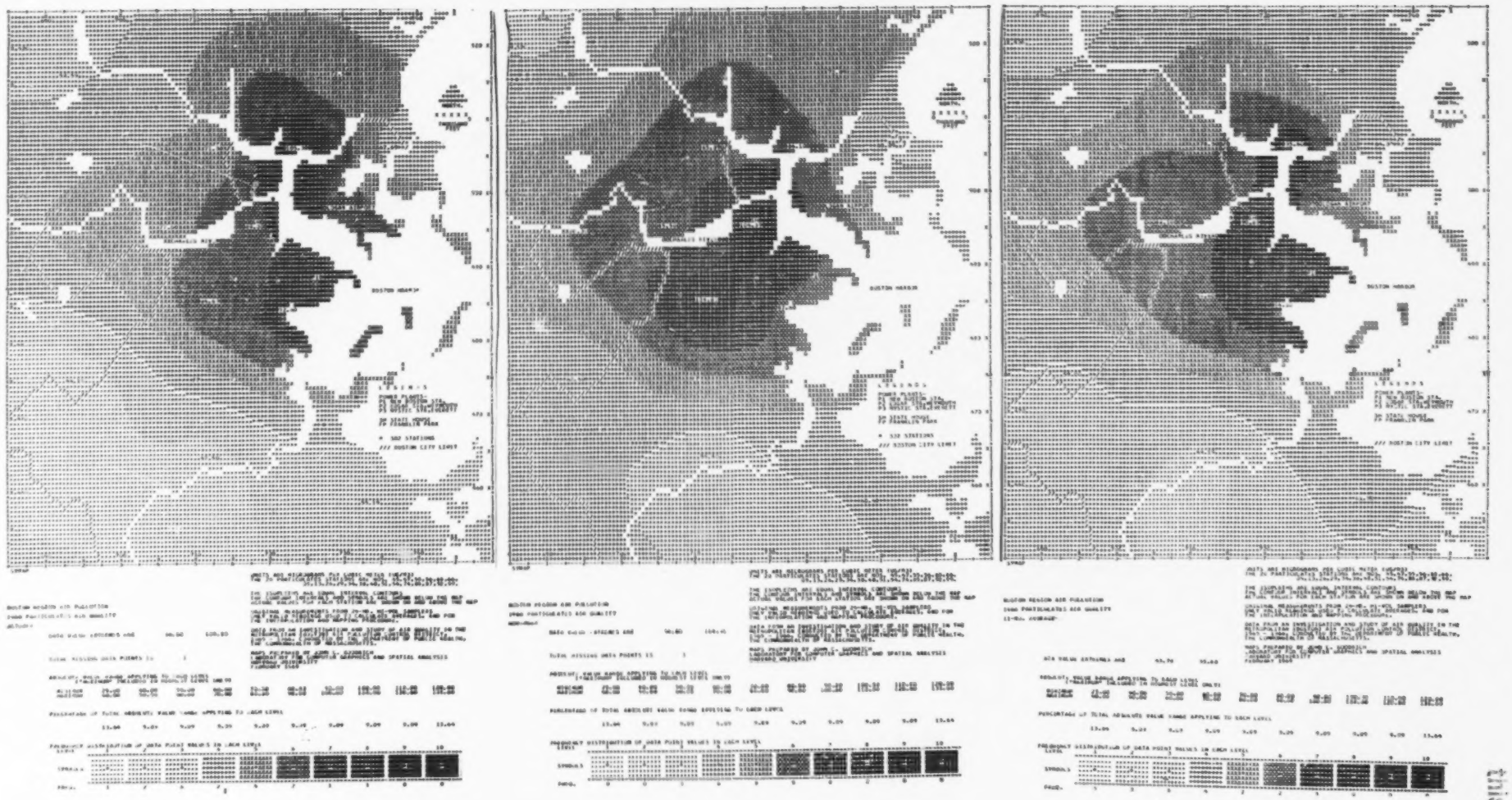


FIGURE J-4

BOSTON REGION STUDY
1966 Concentration of Suspended Particulates
a. October b. November
c. 11-month Average

Details of illustrations in this document may be better studied on microfiche

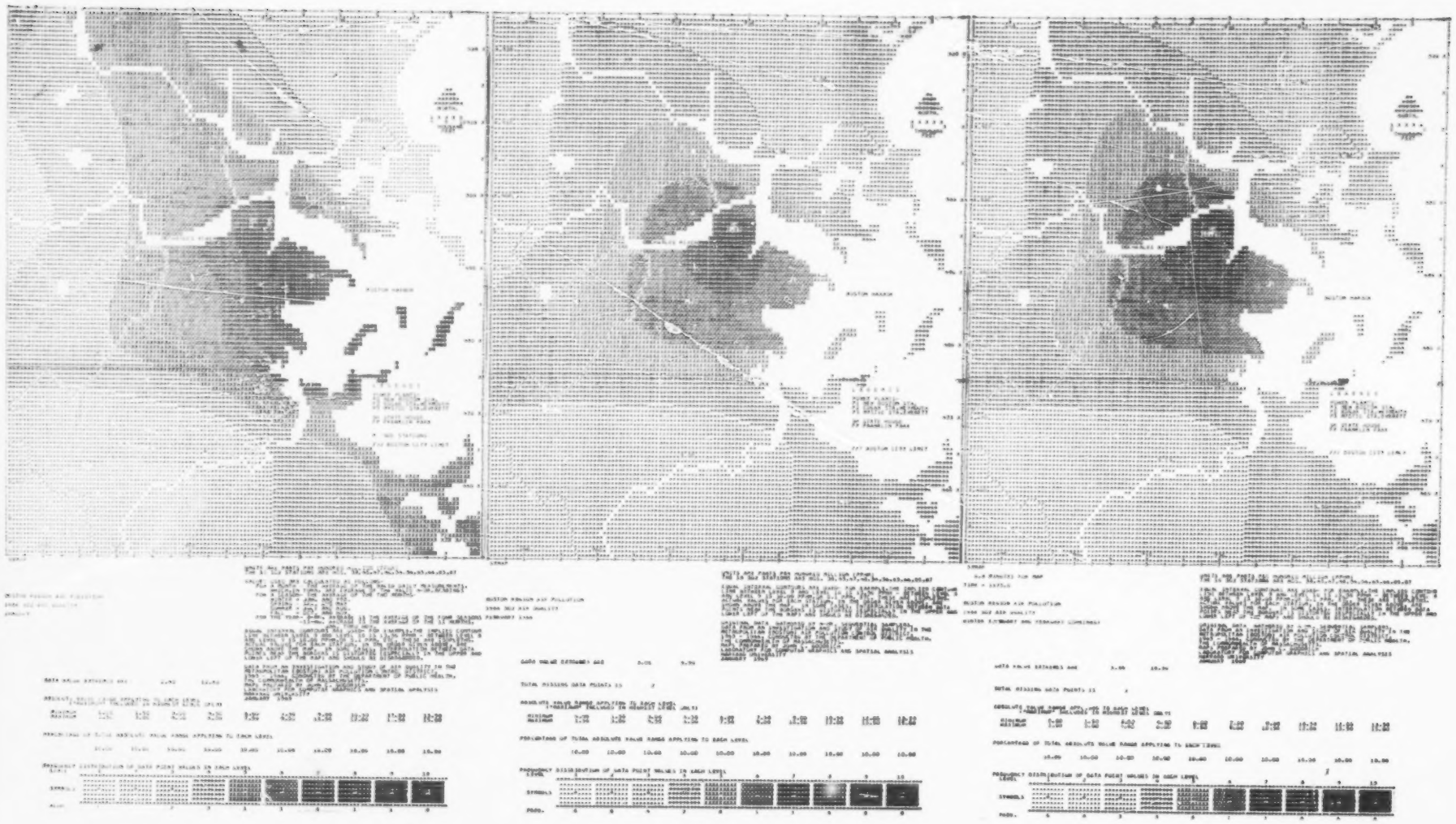


FIGURE J-5

BOSTON REGION STUDY
1966 Concentration of SO_2
a. January b. February
c. Average of a. and b. (Winter)

Details of illustrations in this document may be better studied on microfiche

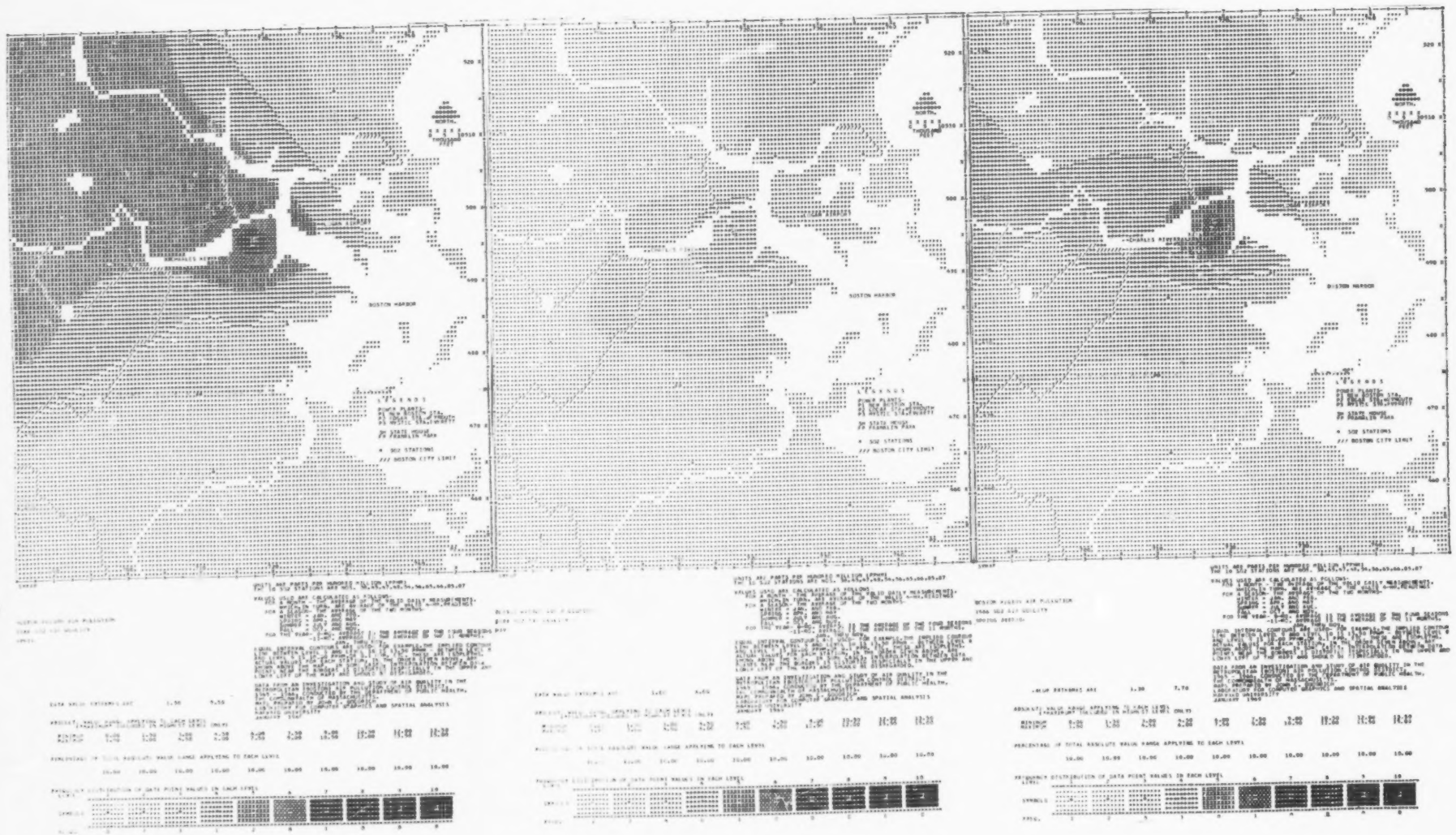


FIGURE J-6

BOSTON REGION STUDY
1966 Concentration of SO_2
a. April b. May
c. Average of a. and b. (Spring)

Details of illustrations in this document may be better studied on microfiche

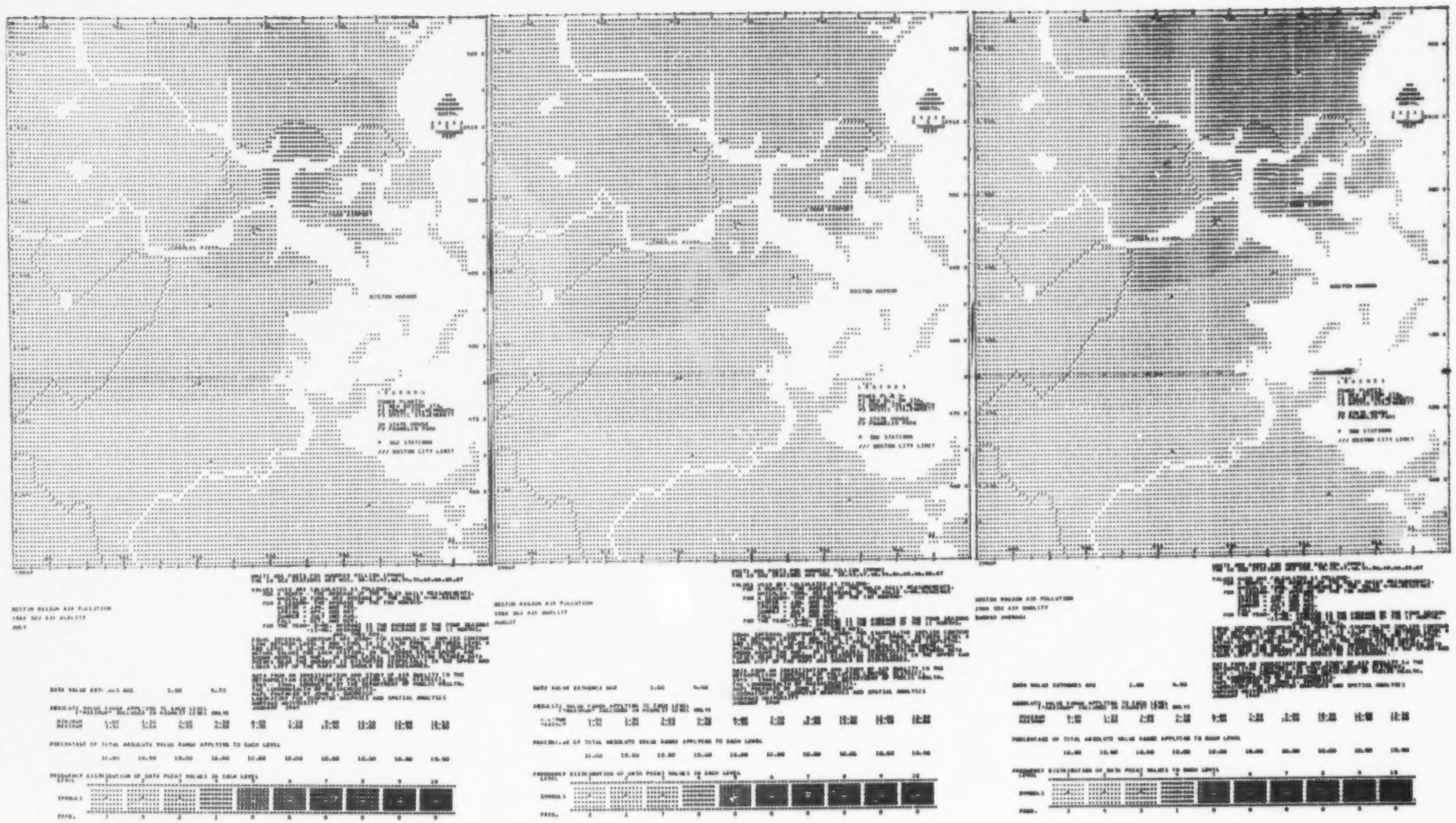


FIGURE J-7

BOSTON REGION STUDY
1966 Concentration of SO_2
a. July b. August
c. Average of a. and b. (Summer)

Details of illustrations in this document may be better studied on microfiche

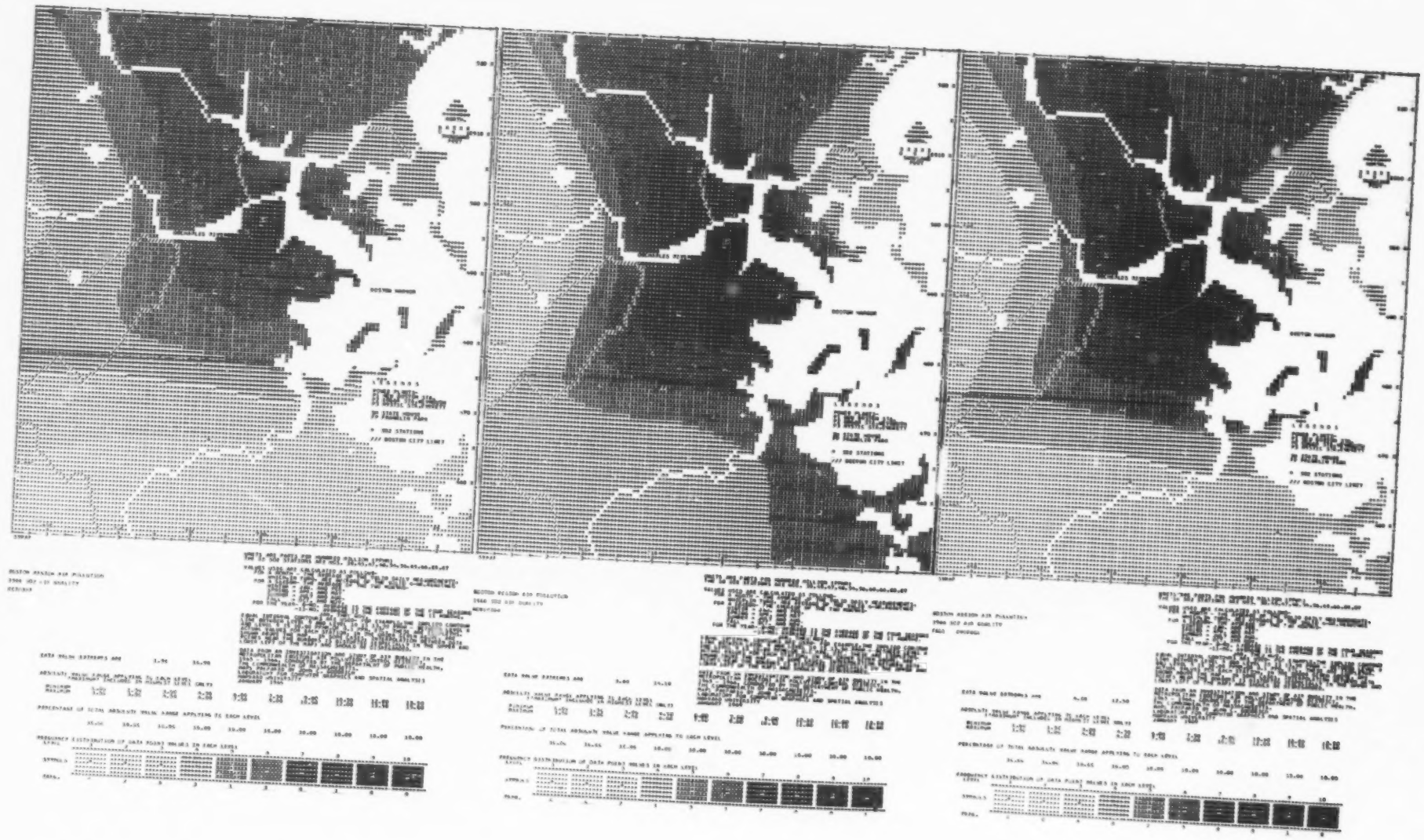


FIGURE J-8

BOSTON REGION STUDY
1966 Concentration of SO_2
a. October b. November
c. Average of a. and b. (Fall)

Details of illustrations in this document may be better studied on microfiche

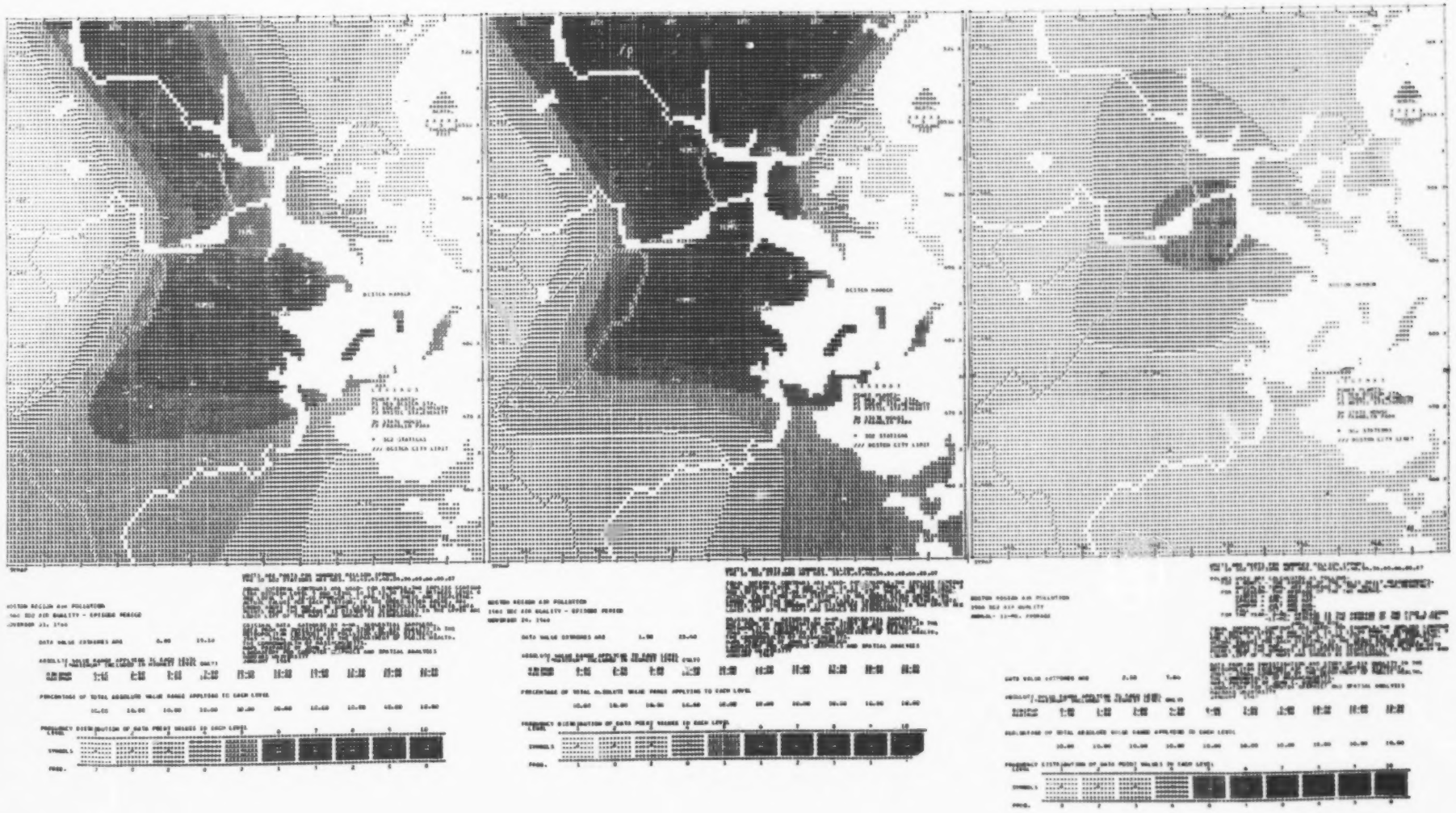


FIGURE J-9

BOSTON REGION STUDY
1966 Concentration of SO_2
a. Episode Period — November 21, 1966
b. Episode Period — November 24, 1966
c. January-November (11-month) Average

This document may be better studied on microfiche

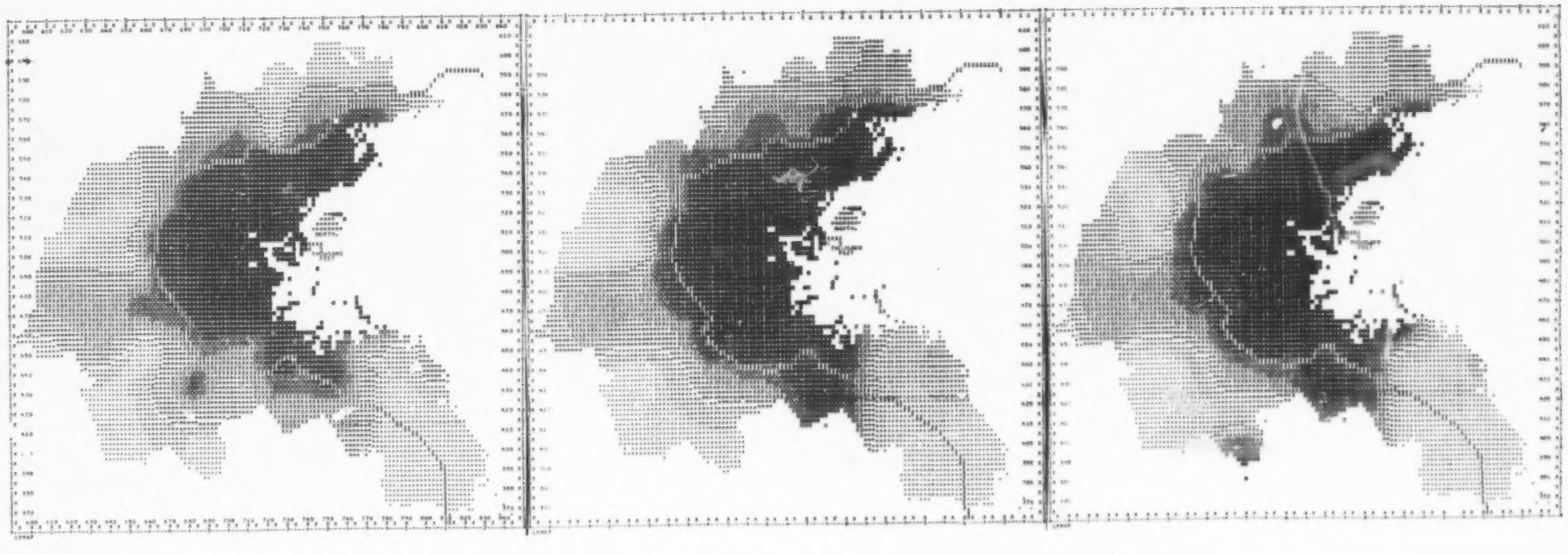


FIGURE J-10

BOSTON REGION STUDY
Development of Emission Inventory
a. Population Density by Towns
b. SOx Emissions, Average Day
c. Suspended Particulate Emissions — Average Day

Details of illustrations in this document may be hard to studied on microfiche